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Avoid Blackouts: Distributed Generation CHP Applications for Research Laboratory Buildings – A Case Study

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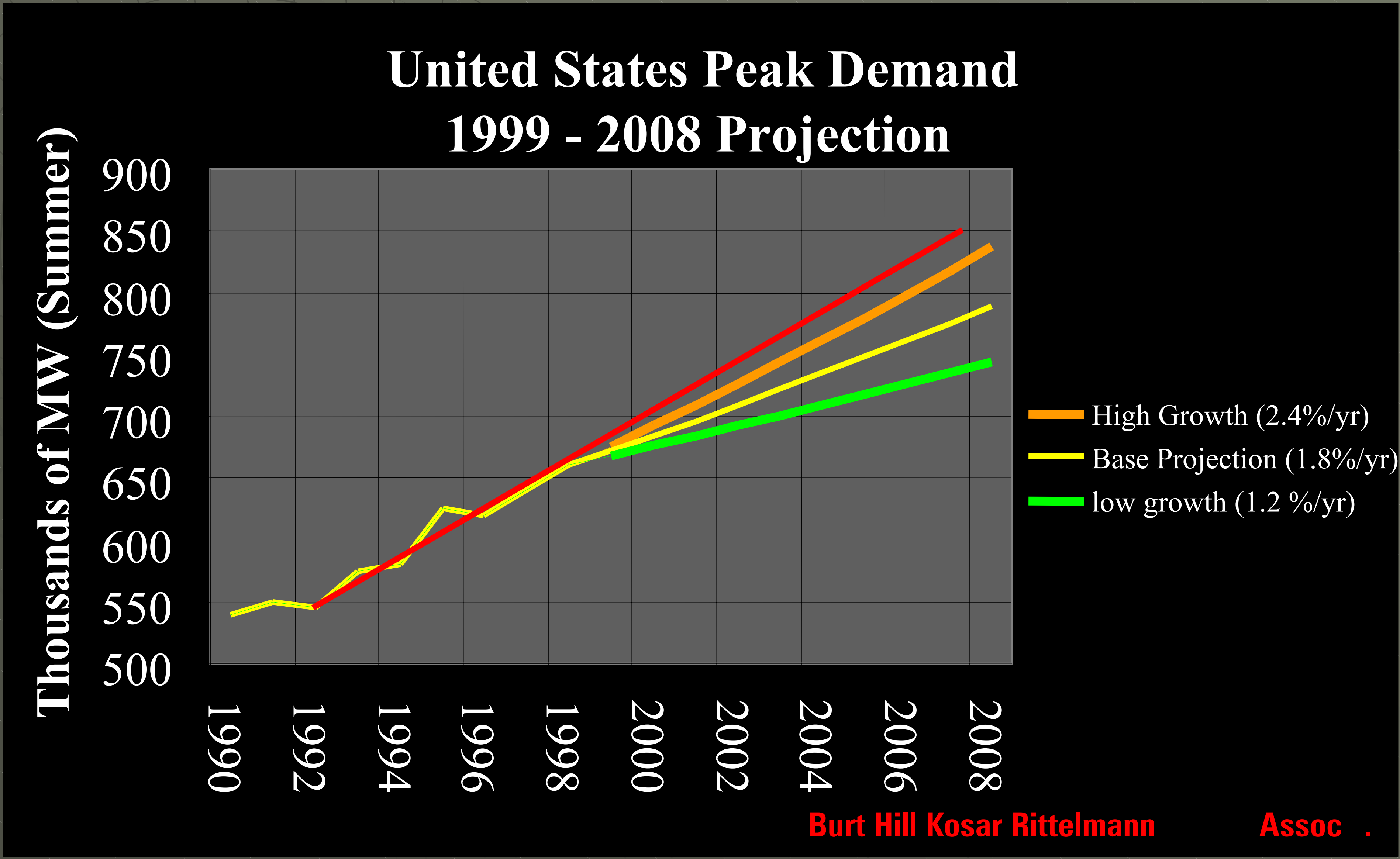
Fact:
The Reliability of Power Supply is Deteriorating

- Actual growth in recent years has been significantly higher than projections for the same period.
- A strong economy continues to drive growth in electrical demand.
- Current projections call for a 1.9% annual growth in elec. energy use, and a 1.8% annual growth in demand…… This is substantially <u>less</u> than the last seven years experience.

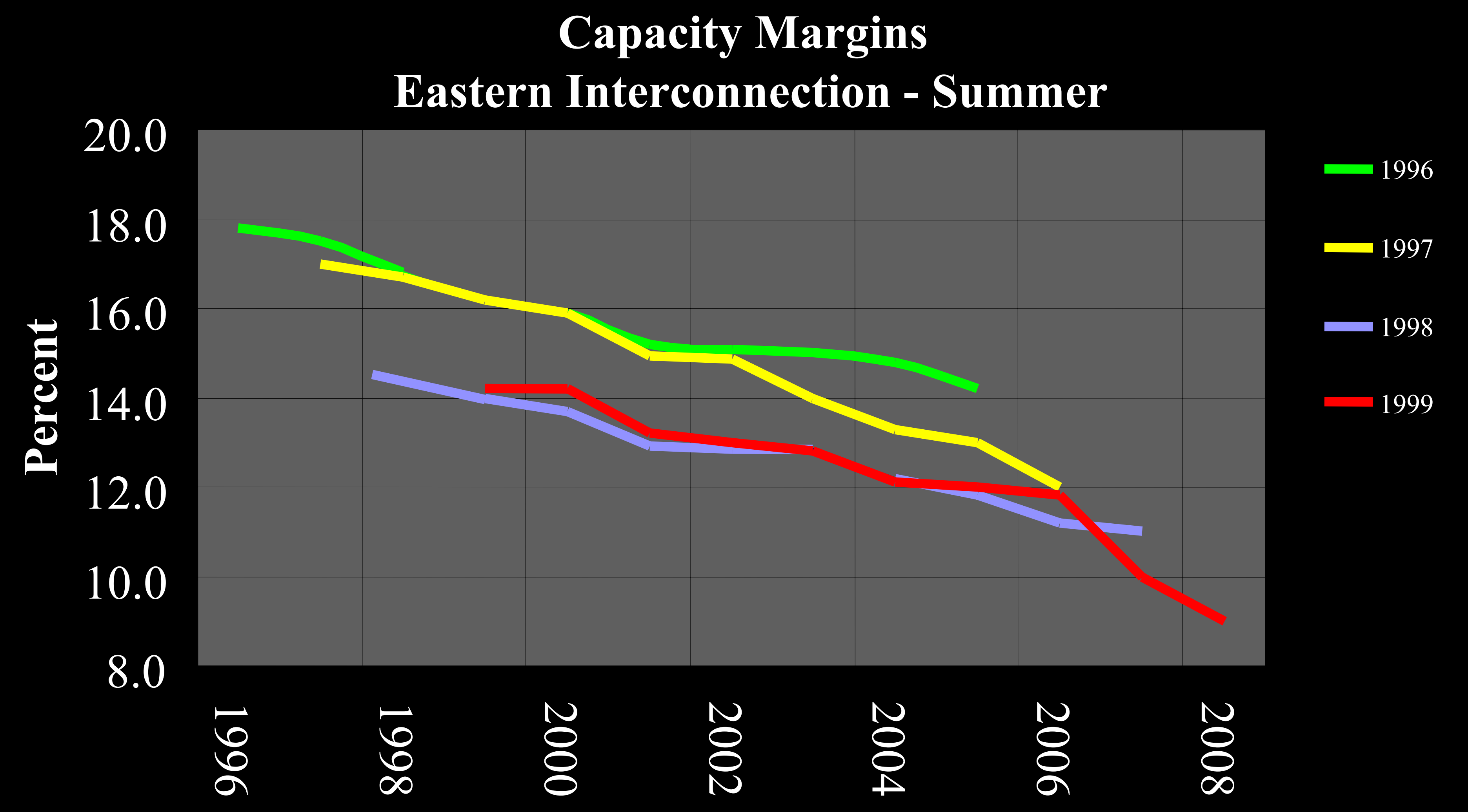
Fact:
The Reliability of Power Supply is Deteriorating

- Generation capacity is dangerously low
- Transmission capacity is erratic nationwide.
- Only a 3.5% increase in transmission circuit miles is planned for the next 10 years.
- We are already dependent upon demand diversity and grid interconnections to prevent brownouts or rolling blackouts.

Projected Demand



Low Regional Capacity Margins



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Fact:

The Reliability of Power Supply is Deteriorating

- The bandwidth of forecasts is getting much wider due to increasing uncertainties.
- Capacity margins are expected to fall from 19% in1998 to 9% in 2008.
- Coupled with decreasing capacities in transmission interconnect, this will likely cause a 20 to 30 times increase in 1998 power outages.

Power Failure

- Recent power failure of 2003 cost $4 to $6 billion
  - Significant effect on economy
- Most emergency generators did not provide sustained power
  - Emergency generators are for life safety, typically 2 hours
  - Many generators did not get adequate fuel supply for sustained operation
  - Some generators could not reject heat on continuous basis because of poor support infrastructure

Fact:
The Reliability of Power Supply is Deteriorating

- 1998 power outages cost U.S. businesses a reported $29 billion. The unreported costs are estimated to be many times this amount.
- By 2008 these losses are likely to exceed $1.5 Trillion.
- The U.S. electrical industry is already depending on the forecasted generation construction of the IPP (Independent Power Producers) to halt the slide in capacity margins

Mission Critical Architecture

- What constitutes poor performance in mission-critical facilities?
  - Loss of data
  - Loss of environmental control
  - Loss of process control
  - Loss of any of the human senses
  - Loss of communication (information flow)
  - Gradual compromise of human abilities / sensation

Mission Critical Architecture

- What causes ALL of these things to happen?
  - Loss of ELECTRICAL POWER.
- What causes MOST of these things to happen?
  - Loss of COMMUNICATIONS.
- What causes MANY of these things to happen?
  - Human Failure
    - Stress
    - Fatigue
    - Loss of senses
    - Slow degradation of performance

Background

- Advancements in information technology have transformed many facilities into Mission-Critical Category
- Research Laboratories are no exception
  - Generations of research animal colonies represent priceless assets
  - Critical long-term experiments represent very high cost of research

Background

- Research labs need to maintain critical temperature for research animals
  - Very close temperature tolerances
  - Temperature variations tolerated for very short time
- More and more functions are automated, therefore enormous amounts of data is collected
  - Disruption is very costly in terms of time and money

Power Failure

- For sustained outage, a very reliable source of power and fuel supply is required
  - Typical backup generators use diesel fuel, which must be transported to the site. This may be difficult in times of large power failures
- Studies at CMU indicate that future power failures may be larger than predicted *(IEEE Spectrum August 2004)*

On-site Power Generation

- On-site distributed power generation using natural gas, is a reliable option
  - High efficiency of fuel use, typically 75% for combined heat and power. (central generation plants are 38%)
  - Better and predictable power quality
  - Societal benefits in term of reduced pollution
  - In-line with the U. S. National Energy Policy, 2001

Presentation Outline

- Overview of Mission-Critical facilities
- Case study for a bio-medical research lab
  - Micro turbine power generation
  - Desiccant cooling CHP system
  - System performance
  - Environmental benefits
  - Total cost of ownership (LCC cost)
  - A new decision making process –*Modified Deplhi Method*
- Conclusions

Mission-Critical Buildings/Facilities

- Power Interruption Cost Variation for the duration of interruption

Cost: $/kW (installed)			
Sector	Duration of Interruption		
	20 min.	1.0 Hour	4.0 Hours
Industrial	6.29	13.93	29.94
Commercial	4.74	12.87	44.37
Residential	0.03	0.15	1.64
Transportation	8.91	16.42	45.95

Source: PNNL-13797, February 2002

Mission-Critical Buildings/Facilities

- Users with High Cost of Power Interruption

Cost: $/kW (installed)			
User	Duration of Interruption		
	20 min.	1.0 Hour	4.0 Hours
Oil and gas extraction	81.47	193.88	205.85
Food and kindred products	4.74	15.10	50.52
Insurance agencies/broker services	24.16	29.39	58.49
Eating and drinking establishments	9.47	28.41	147.93
Biomedical Labs	--- Incalculable ---		

Source: U.S. DOE

Mission-Critical Buildings/Facilities

- Cost of Power Outages for Selected Sensitive Power Consumers in Commercial Sector

Users	Average Cost $/Hr.
Cellular Communications	41,000
Phone Ticket Sales	72,000
Airline Reservations	90,000
Credit Card Operations	2,580,000
Brokerage Operations	6,480,000

Source U.S. DOE Strategic Plan for DER, 2000

Electrical Power Reliability

- For mission-critical uses, even a 5-minute interruption with five nines can cost millions of dollars

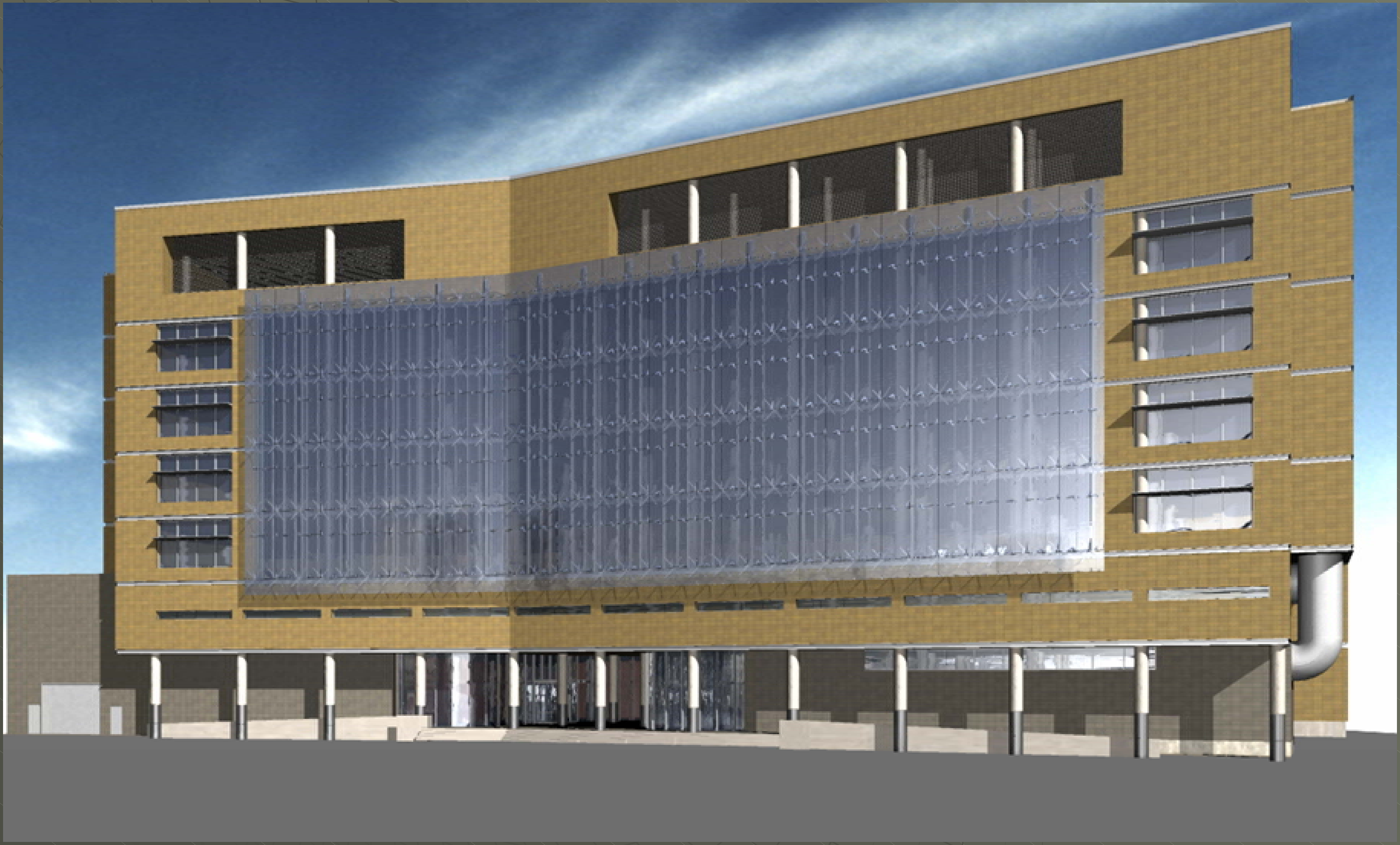
Typical Industry Standards	**Reliability**	**Down Time**
99.999% up time per year	5 nines	5 minutes down time
99.99% up time per year	4 nines	50 minutes down time
99.9% up time per year	3 nines	8 hours down time
99% up time per year	2 nines	3.6 days down time

Source: CIO Magazine, September 1, 2002, page 58

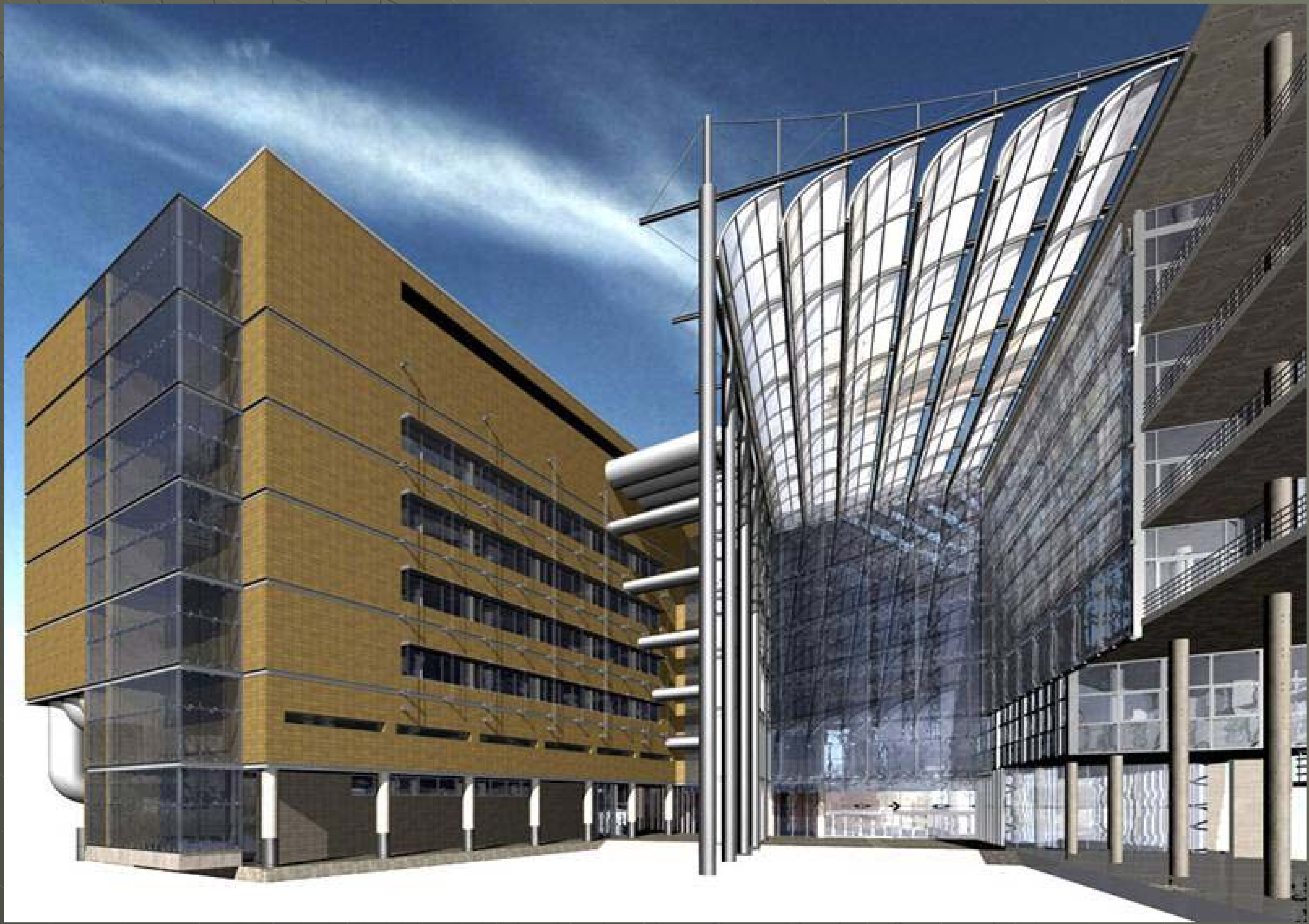
Case Study

Institute of Molecular Medicine Laboratories,
University of Texas, Houston, TX

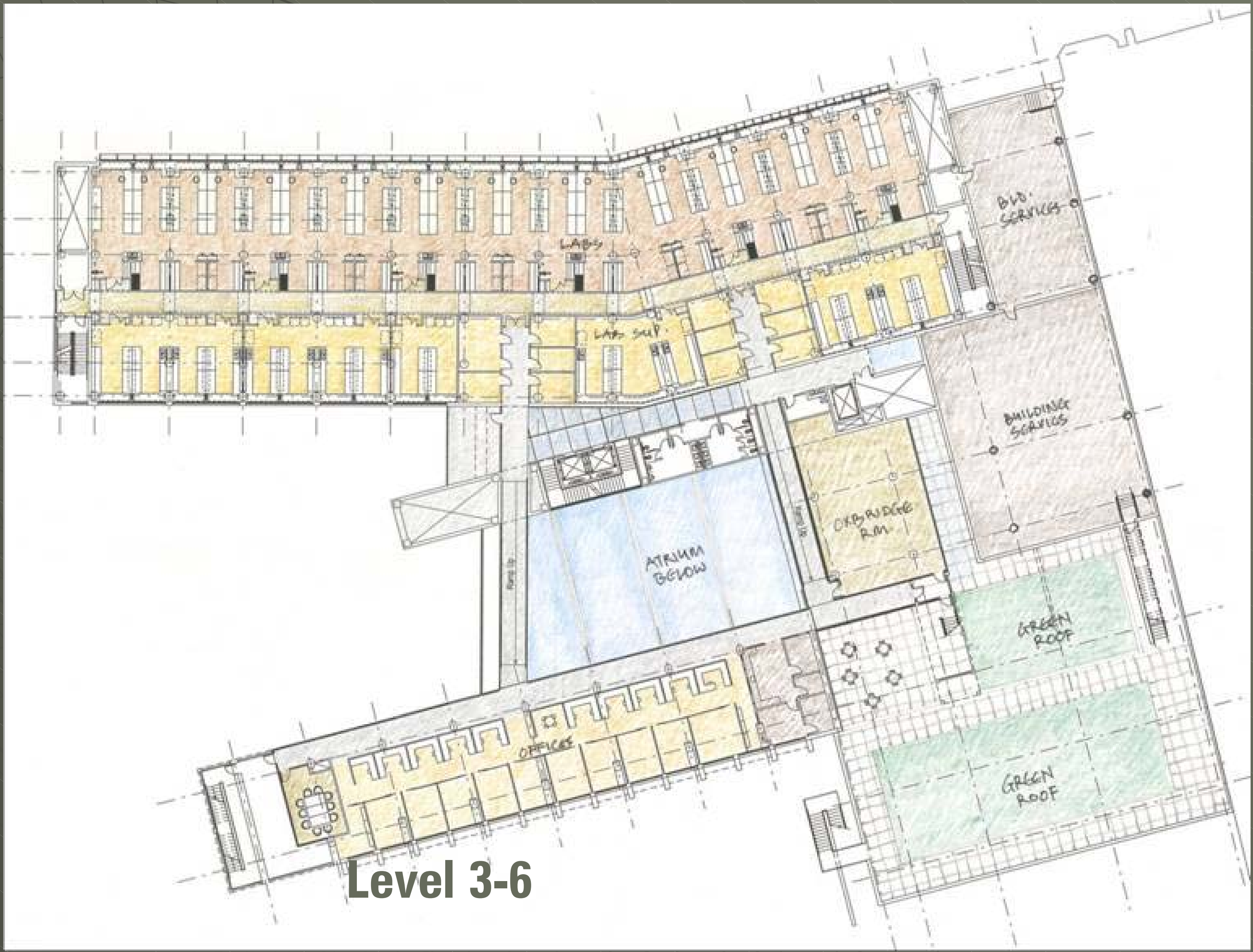
Case Study



Case Study



Case Study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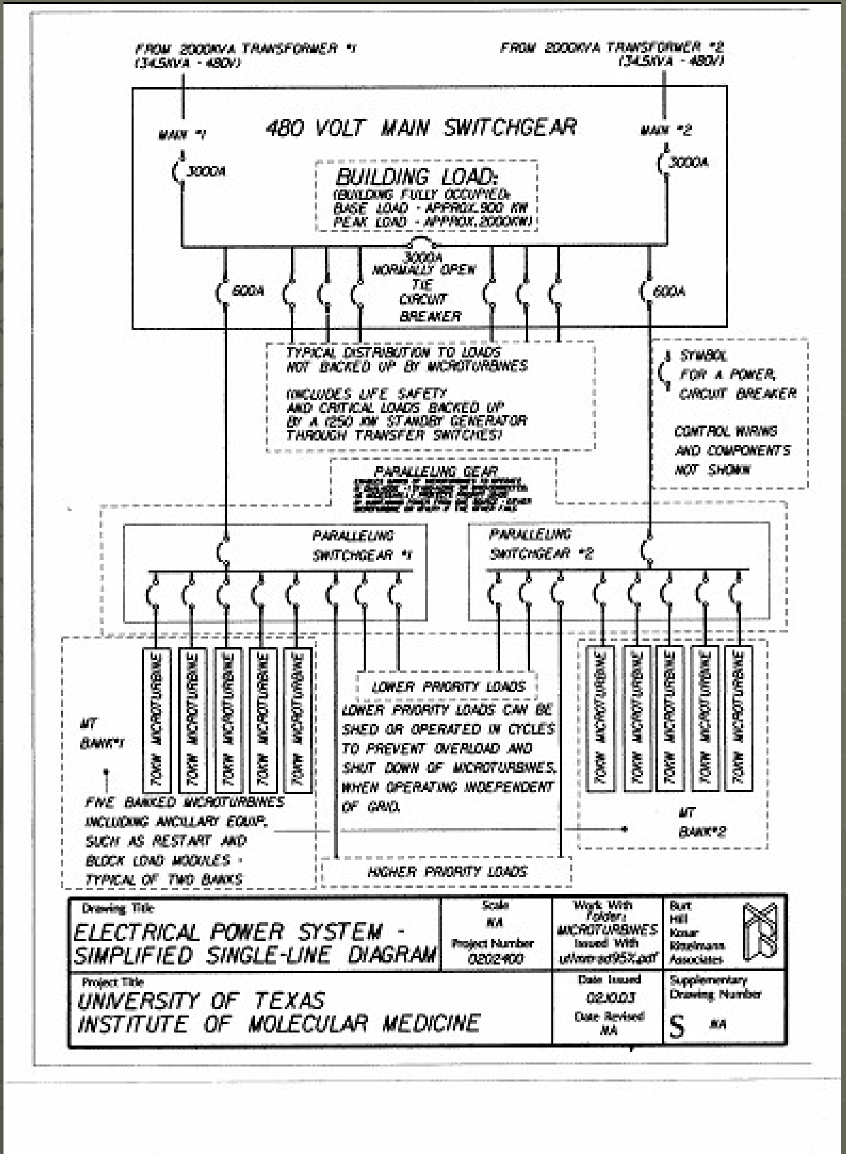
Characteristics of Micro Turbines Considered

- **Ingersol Rand 70 KWe**: These micro turbines are conventional micro turbines with gearbox and synchronous generator
- **Capstone 60 KWe:** Designed for DER applications with USDOE support. These turbines use very simple mechanical system, single shaft and a high speed generator. Generation is at RF frequency, and is used after rectification and inversion to AC.

Micro Turbine Connection-Scheme 1 – Ingersol Rand Turbines

- **This arrangement will be truly like a utility type generation and connection**

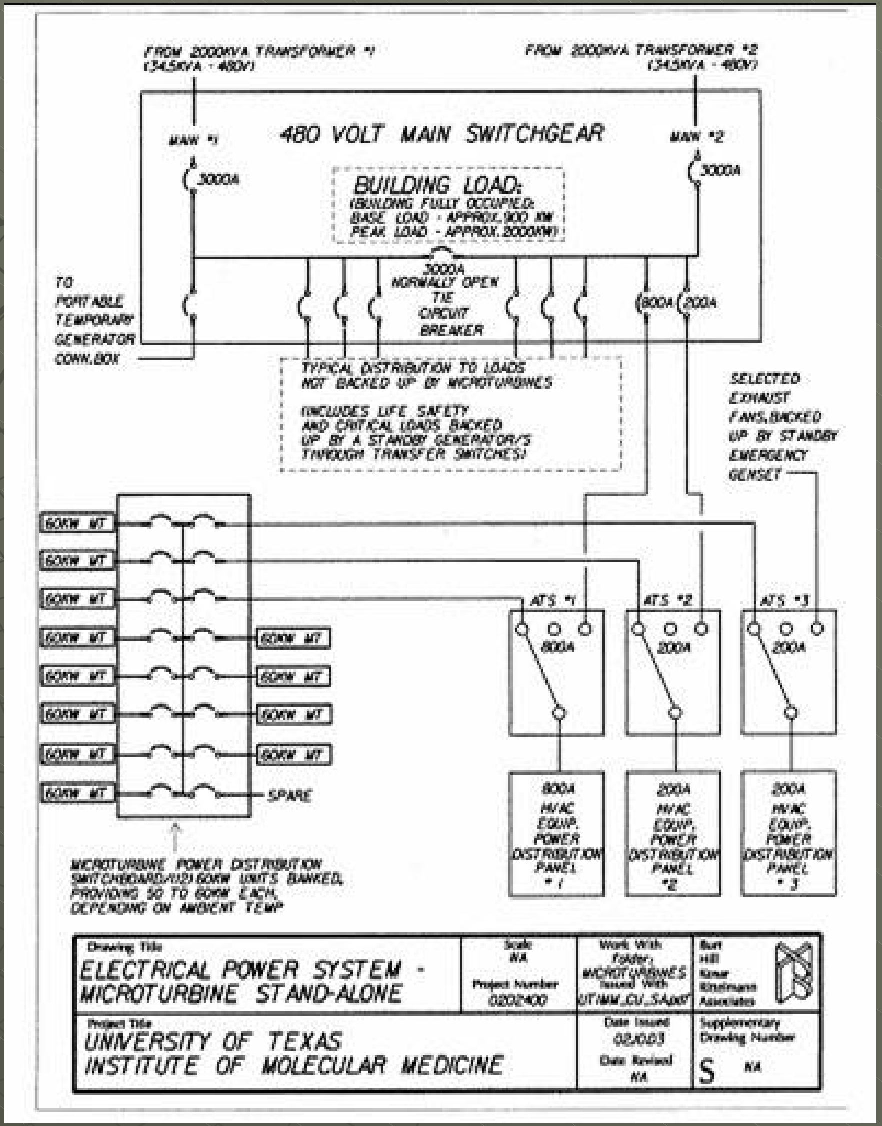


Micro Turbine Connection Scheme 1 – Ingersol Rand Turbines

- The reason to use this scheme was to provide power generation with ultimate flexibility and redundancy.
- Ten power turbines were used in two banks of five turbines. These turbines were connected to two paralleling and synchronizing gears. The electrical system will connect and disconnect from utility in close transition without power interruption.

Micro Turbine Connection- Scheme 2 Capstone 60 KW Turbines

- Scheme 2 Micro Turbine Configuration



Micro Turbine Connection Scheme 2 - Capstone 60 KW Turbines

- Twelve Capstone micro turbines are used
- These turbines provide power to three transfer switches that serve three different loads.
  - **Two transfer switches have the electric utility as back up, one has the emergency generator as back up**
- The scheme uses the turbines operating in a utility-independent configuration thus the power interruption has no effect on turbine operation

Selected Electric Generation Scheme

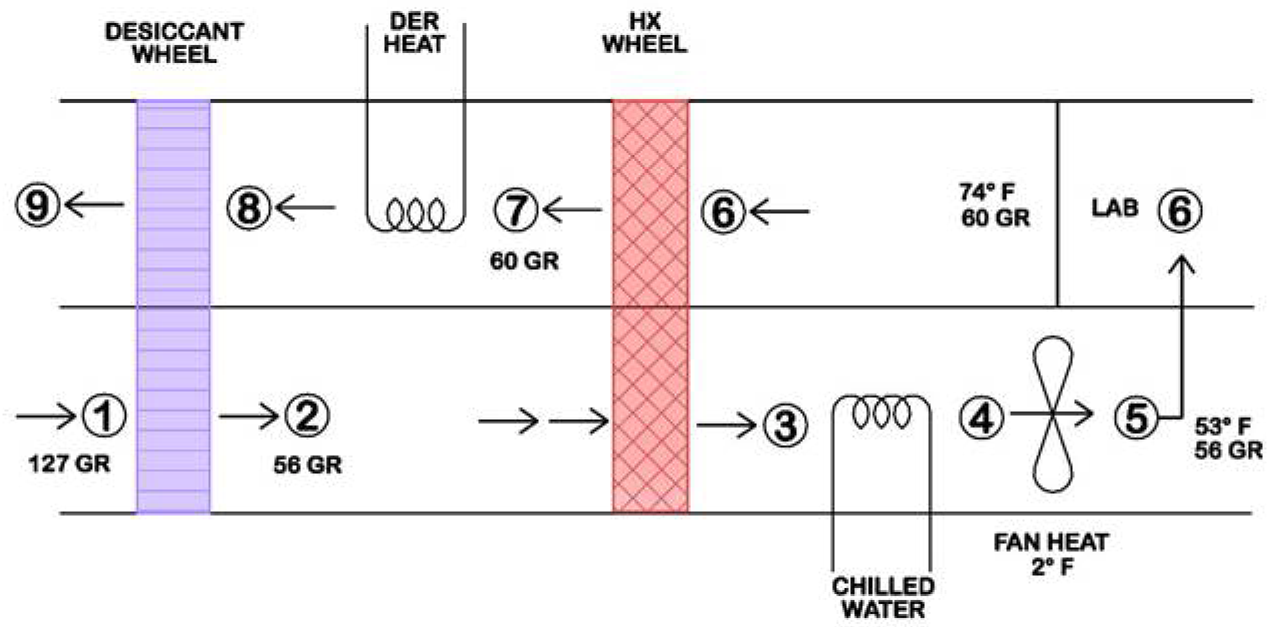
- The project selected Scheme 1 because:
  - It provided parallel operation with the utility
  - Utility outages did not require shutting down the turbines
- The Capstone Turbine at the time were line commutated and would shutdown and restart with utility interruption
  - Scheme 2 considered Utility independent operation

CHP System Description

- Base electrical load of 700 KWe is supplied by ten 70 KWe micro turbines.
- Micro turbines are paralleled with the electric utility.
- Air is supplied by six air handlers of 25,000 CFM each.
- Each air handler is fitted with a desiccant wheel.
- The desiccant will be a combination molecular sieve / silica gel.
- All of the latent cooling load is removed by desiccants.
- The latent cooling load in Houston is 54% of the total.

System Schematic

- Point 1, outdoor air Process 1-2, moisture removal, air is dried to 56 gr/lb
- Process 2-3, heat exchange, air at pt. 3 about 85F.
- Process 3-4, sensible cooling with chilled water
- Process 4-5, fan heat, raises temp by 2F



SCHEMATIC OF THE DESICCANT SYSTEM USED FOR THE SIMULATION

System Benefits

- Better fuel use efficiency
- Higher quality power.
- Greater electric reliability for mission-critical loads.
- Latent cooling load removed with waste heat
- Sensible cooling is much more efficient
- Much higher indoor air quality.
  - **Desiccants allow a dry air system. No wet coils, no condensate drip pans. No place for mold and mildew to grow.**
  - **The hot desiccant wheel is also a bactericide.**

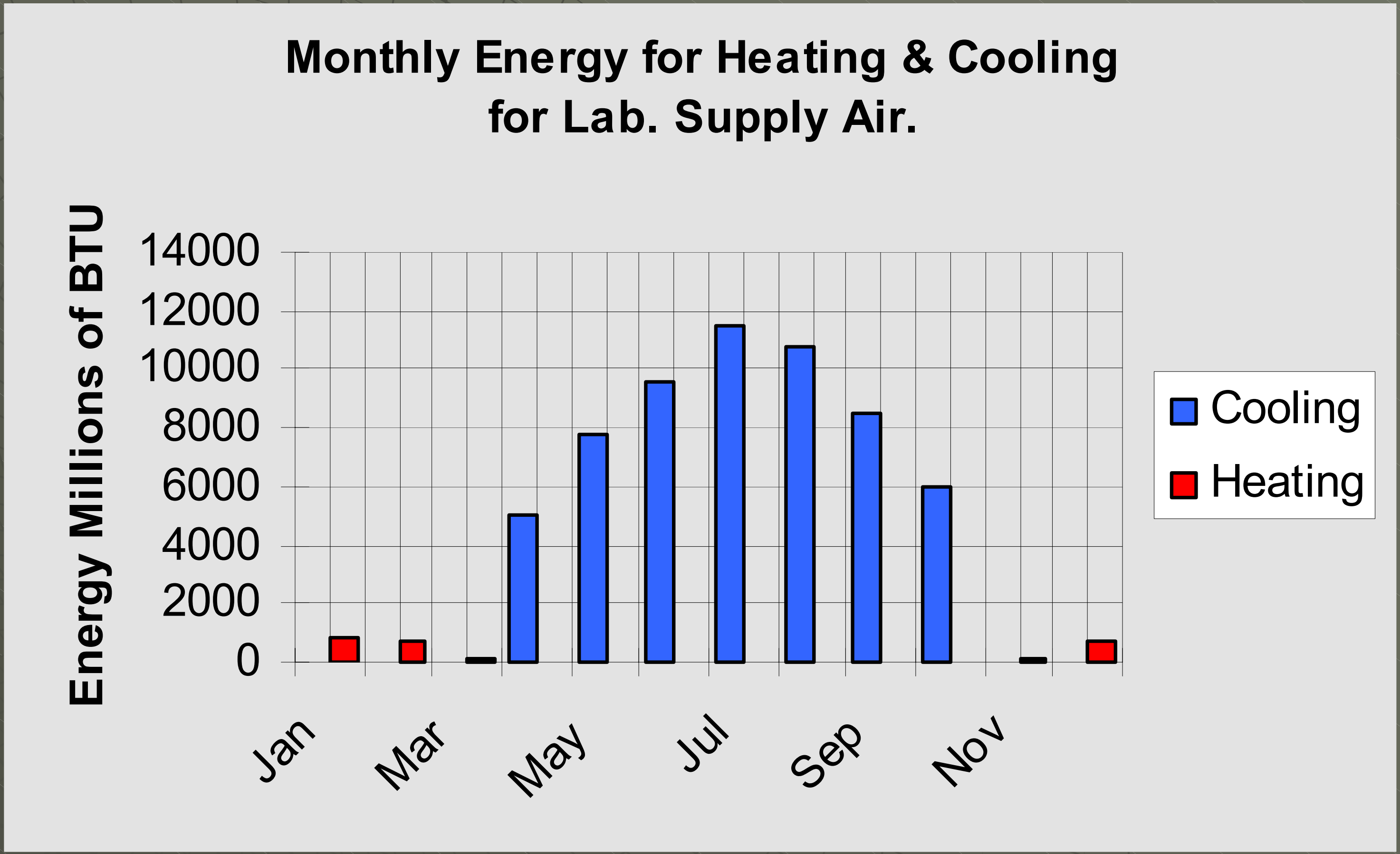
System Modeling

- Design conditions for Houston;
  - Cooling – 97^0 F, 127 gr. / Lb.
  - Lab interior condition – 74^0 F, 60 gr. / lb.
- Visual DOE 2 was the base building modeling tool.
- TMY2 Weather data was used.
- Load data from DOE 2 was used as input to TRNSYS for the desiccant simulation model.
- The adsorption and desorption was assumed to be adiabatic.

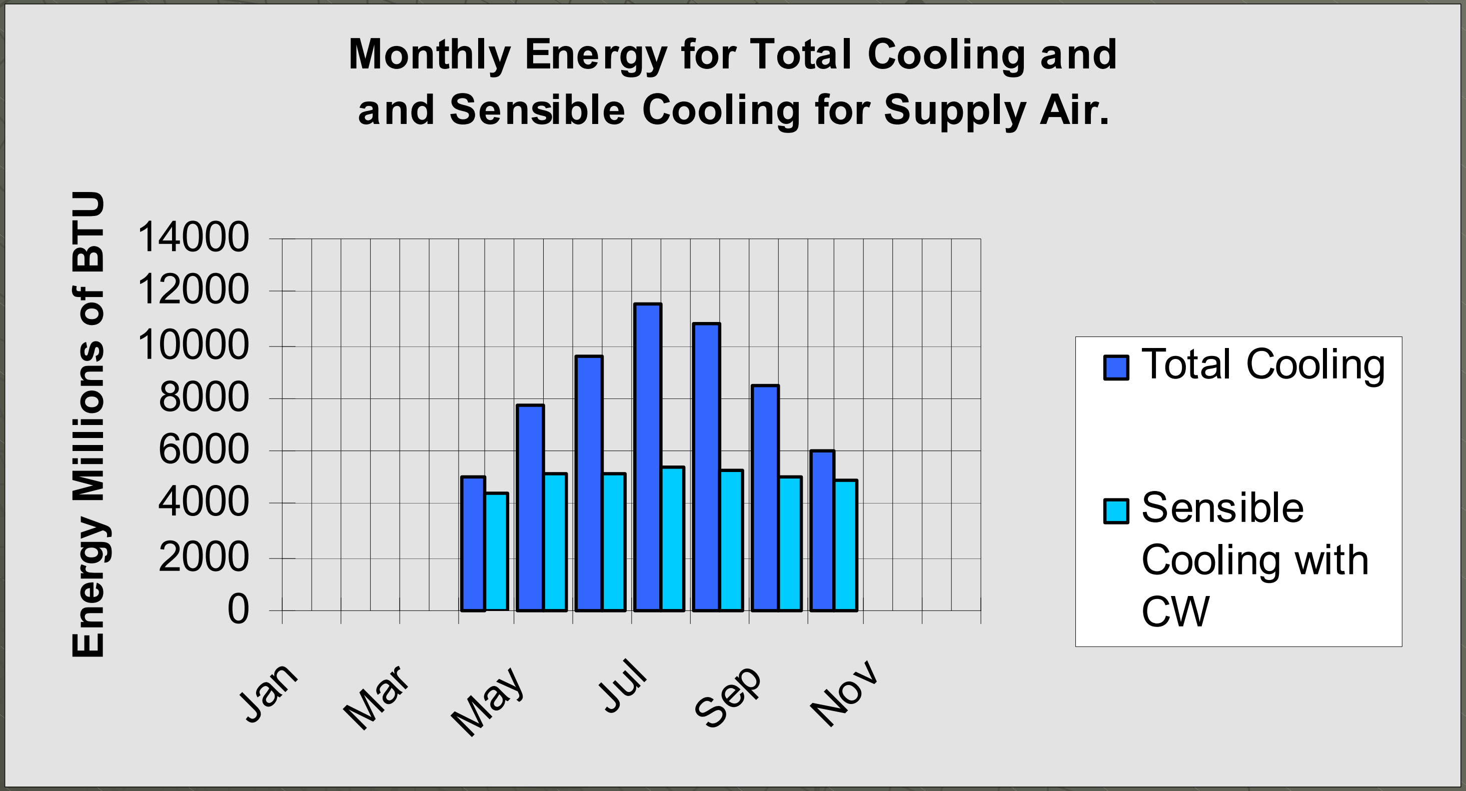
Specifications of MicroTurbine used in the Analysis:

- Ingersol Rand Micro Turbine
- Power: 70 KWe
- Exhaust heat, (HHV) 14,050 Btu / KWh
- Efficiency at HHV: 27%
- Exhaust temperature: 450^0 F
- Exhaust mass flow: 1.6 lb. / sec.
- Total exhaust energy: 250,000 Btu / Hr.
  - Turbine exhaust goes directly to the desiccant wheels
  - Turbine heat to the environment: 35 KW
- Total gas supply: 983,500 Btu / Hr.

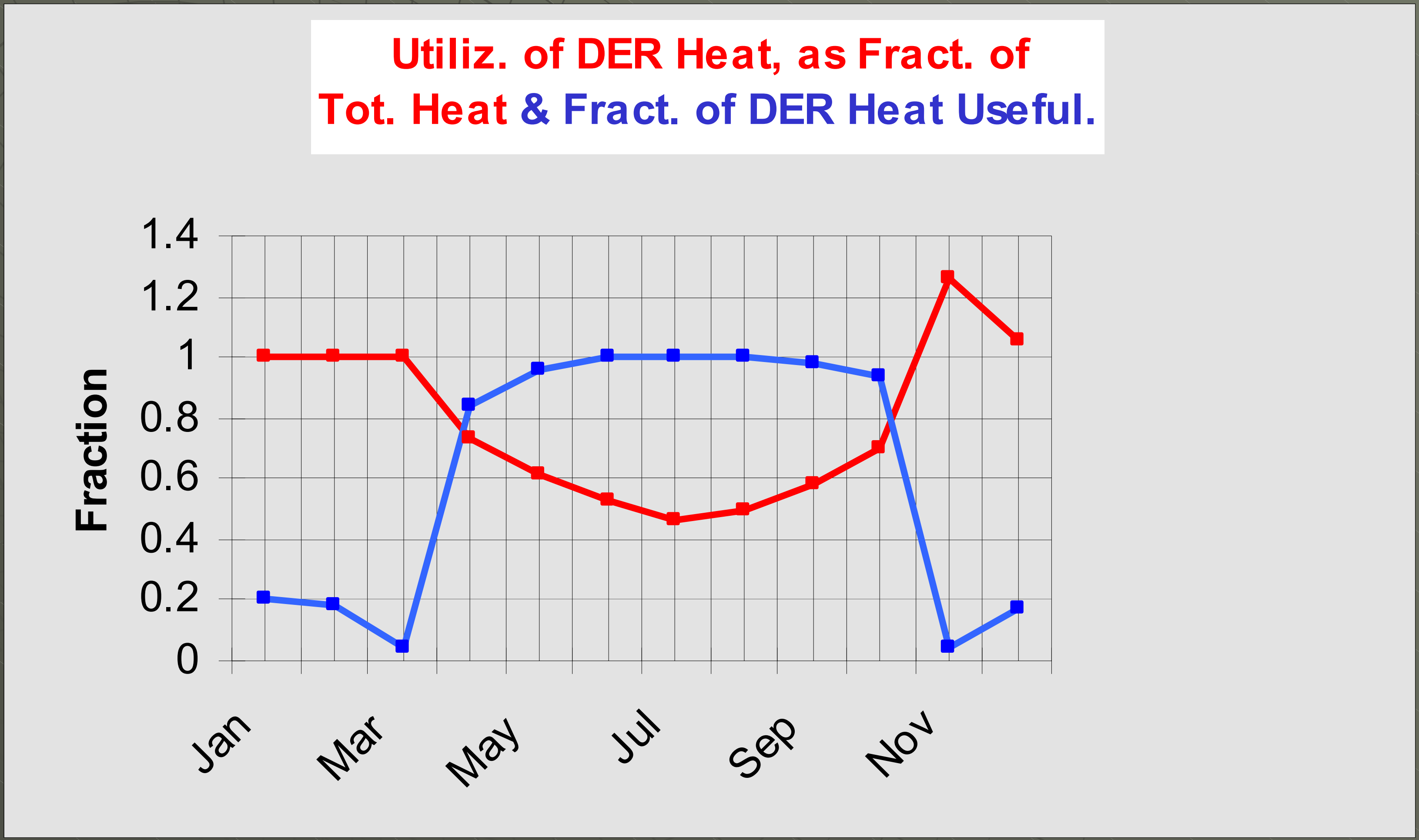
Annual Energy to Condition Lab Supply Air



Relationship of Sensible Load to Total Load



Utilization of Turbine Exhaust Heat



Summary of simulation Results

- Total Cooling Requirements: 29,013 x 10^6 BTU's
- Total Heating Requirements: 4,967 x 10^6 BTU's
- Aux Gas to Desiccants 11,770 x 10^6 BTU's
- Useful Heat from Turbines 20,060 x 10^6 BTU's
- Rejected Heat from Turbines 1,816 x 10^6 BTU's
- Chilled water demand (no desiccants) 1145 Tons
- Chilled water demand (with desiccants) 575 Tons

Annual HVAC Operating Costs – Vapor Compression System

- Cost of electricity for cooling $145,667
- Cost of gas for heating $28,803
- Cost to purchase .7MW base load power $367,920

- Total Annual HVAC costs $542,390

Annual HVAC Operating Costs – Desiccant System

Cost of electricity for sensible cooling	$ 88,714
Cost of gas for desiccant cooling	$ 35,310
Cost of gas for power generation	$258,464
Maintenance cost for turbines	$ 12,664
Total Annual HVAC costs	$395,150

Annual HVAC Operating Costs – Summary

Vapor Compression System	$542,390
Desiccant Cooling System	$395,150
Total Annual HVAC Savings	$147,240

Assumptions for LCC Analysis

- System life: 25 years
- Discount rate: 3.00%
- Analysis is broadly based on NIST Handbook 135 for FEMP
- Energy price indices and discount factors are taken from DOE/NISTIR 85-3273-17
- Electric cost is $0.06/KWH, gas per million BTU, $3.00 for transport gas, $5.50 for regulated gas

Life Cycle Cost Summary

Base Building System LCC	$26.02 Million
Desiccant / Turbine System LCC	$24.19 Million
LCC Savings	$1.83 Million

Environmental Emissions

- Power Generation[1]
  - Sulphur Dioxide SO_2: 19.157 Metric Tons/MW
  - Nitrogen Oxide NO_X: 7.894 Metric Tons/MW

- Gas Boilers[2]
  - Particulates: 0.00095 lbs/million Btu
  - SO_2: 0.00057 lbs/million Btu
  - NO_2: 0.1333 lbs/million Btu

Sources:
1. *Tina M. Kaarsberg, "An Integrated Assessment of the Energy Saving and Emission Reductive Potential for CHP," Northeast, Midwest Institute*
2. *U.S. DOE, Publication DOE/EE-0217, Assessment of Donlee 3000 Horsepower Turbo-Fired XL Boiler*

Comparison of Emissions IMM, Houston, TX

- Base Case Building
  - SO2 30.79 MT/year
  - NOx 13.66 MT/year
- Scheme 1, Desiccant System
  - SO2 0.003 MT/year
  - NOx 0.745 MT/year
- The cost of avoided emissions can be estimated by using Shadow pricing of various pollutants

Shadow Prices for Environmental Pollutants

Pollutant	**Shadow Price US $/kg**
Carbon Dioxide CO_2	$0.017
Sulphur Dioxide SO_2	$1.800
Nitrogen Dioxide NO_X	$1.086
Carbon Monoxide CO	$0.562
Volatile Organic Compounds	$398
Nitrous Oxide NO_2	$2981
Methane CH_4	$170
Source: Oakridge National Lab, 1995, The Effects of Considering Externalities on Electric Utilities Mix of Resources	

The Delphi Oracle

- The Oracle of Apollo at Delphi in ancient Greece
- The temple of Apollo housed the Oracle during the height of its power in the 6th and the 7th centuries BC
  - The Oracle is said to have foretold many occurrences which proved true

The Delphi Oracle

- In its hey-day, the enquirers traveled to Delphi
  - On arrival they offered animal sacrifices
  - After this the enquirers waited their turns for the Oracle consultation
  - Questions were written on lead tablets
  - The message was delivered to the priestess Pythia
  - The priestess would occur incoherent verses which would be translated by poets

The Delphi Oracle

- The Oracle’s interpretations were always obscure and frequently ambiguous
  - The enquirer often returned more mystified then he came
- The philosopher Starbo stated that, “Of all Oracles of the world, Delphi had the reputation of being the most truthful”

Delphi Decision Making Process

- Adopted to technology forecasting in 1944
- The basic premise is that in the absence of physical science laws, the testimony of "experts" is permissible
- The technique is used to rate projects with less than the best available information
- Allows the consideration of quantitative and non-quantitative data in the same decision making process.

Modified Delphi Decision Making Process

- Delphi technique was modified for use at IMM project
- Group selects decision making criteria
- Group ranks criteria in order
- Group assigns weight to criteria
- Designers rate each system relative to criteria
- Select one or more criteria that are quantifiable.
- Value all other criteria to that index

Delphi Process Results
Group-Selected Criteria

- Research Envir./Productivity
- Operations Cost
- Power Reliability
- Indoor Air Quality
- Constructability
- Power Quality
- Attract Research Grants
- First Cost
- Schedule
- Societal Costs
- Fund Raising

Group Weighting of Criteria

Delphi Process Results	Wt.
Research Envir./Productivity	1.00
Operations Cost	0.90
Power Reliability	0.80
Indoor Air Quality	0.80
Constructability	0.80
Power Quality	0.50
Attract Research Grants	0.45
First Cost	0.45
Schedule	0.45
Societal Costs	0.40
Fund Raising	0.20

Group Weighting of Criteria
Delphi Process Results

- An important evaluation criteria is the annual maintenance cost for the building
  - For the IMM building this cost was calculated as $2.86/sq ft. gross per year
  - All the evaluation criteria were further weighted with this number

Delphi Process Results

	Wt.	Val.
Research Envir./Productivity	1.00	2.86
Operations Cost	0.90	2.86
Power Reliability	0.80	2.86
Indoor Air Quality	0.80	2.86
Constructability	0.80	2.86
Power Quality	0.50	2.86
Attract Research Grants	0.45	2.86
First Cost	0.45	2.86
Schedule	0.45	2.86
Societal Costs	0.40	2.86
Fund Raising	0.20	2.86

Delphi Process Results	Wt.	Val.	Mult.
Research Envir./Productivity	1.00	2.86	2.860
Operations Cost	0.90	2.86	2.574
Power Reliability	0.80	2.86	2.288
Indoor Air Quality	0.80	2.86	2.288
Constructability	0.80	2.86	2.288
Power Quality	0.50	2.86	1.430
Attract Research Grants	0.45	2.86	1.287
First Cost	0.45	2.86	1.287
Schedule	0.45	2.86	1.287
Societal Costs	0.40	2.86	1.144
Fund Raising	0.20	2.86	0.572

Building Options Rating by Professionals

- The project design professionals rated the Base Building and Scheme 1 for IMM building with respect to the criteria developed by the owner group
- This evaluation provided an objective rating on technical basis

Professionals' Rating, Base Case and Scheme 1

Delphi Process Results	Wt.	Val.	Mult.	Base	Sch 1
Research Envir./Productivity	1.00	2.86	2.860	4	6
Operations Cost	0.90	2.86	2.574	4.5	5.5
Power Reliability	0.80	2.86	2.288	4.5	5.5
Indoor Air Quality	0.80	2.86	2.288	3.5	6.5
Constructability	0.80	2.86	2.288	6.5	3.5
Power Quality	0.50	2.86	1.430	4	6
Attract Research Grants	0.45	2.86	1.287	4	6
First Cost	0.45	2.86	1.287	6	4
Schedule	0.45	2.86	1.287	6	4
Societal Costs	0.40	2.86	1.144	2.5	7.5
Fund Raising	0.20	2.86	0.572	4	6

Delphi Process Results

	Comp. Score	% of total
Base Building Option	26,445	65%
Desiccant / Turbine Option	30,640	76%
Maximum Possible Score for the Building	40,500	100%

Evaluation Process Results – Summary

Building	LCC	Delphi
Base Building	$26.02 Mil	26,445
Scheme 1	$24.19 Mil	30,640

Scheme 1 is the winner both on the LCC basis as well as for non-quantifiable criteria using Modified Delphi Method

Conclusions

- The Micro Turbine CHP system evaluated, provides operation, independent of the electric utility
- Fuel is natural gas, therefore delivery of the fuel during a sustained utility outage is more reliable
- The system allows Mission-Critical lab systems to continue to operate during blackouts!

Conclusions

- Life Cycle Analysis (LCC) also known as the Total Annual Cost of Ownership (TACO), is only one of the criteria for rating projects
- Non-quantifiable criteria such as the ones discussed, are rated more subjectively using a Modified Delphi Technique

Conclusions

- Some building owners are beginning to consider the evaluation technique as discussed
- Delphi Evaluation technique has long been used in:
  - The evaluation of technology
  - For medical research
  - Other cutting edge processes where physical data does not exist

Thank you
For your attention

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